

FROST EFFECTS CONSIDERATIONS FOR HIGHWAY PAVEMENT DESIGN
IN THE WESTERN UNITED STATES

By

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General

The Western United States geographically encompasses an area of climatic extremes. Elevations for regularly used highways range from below sea level to over 11,000 feet. The latitude varies from semitropical areas to the 49th parallel or an area where winters can be very severe except as modified by the Japanese current along the Pacific Coast. Rainfall varies from less than 1 inch per year to more than 150 inches per year. With these variations in precipitation and temperature it is apparent that frost effects would likewise vary through very great extremes.

Figures 1 and 2 show the mean minimum and maximum temperatures for the month of January. Figure 3 shows the range of the mean annual precipitation for the Western United States. A study of Figures 1 and 2 will indicate the very extensive areas subject to daily freeze and thaw conditions.

The questionnaire submitted to all highway departments in the WASHO, with the exception of Alaska and Hawaii, requested

UNITED STATES
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WEATHER BUREAU

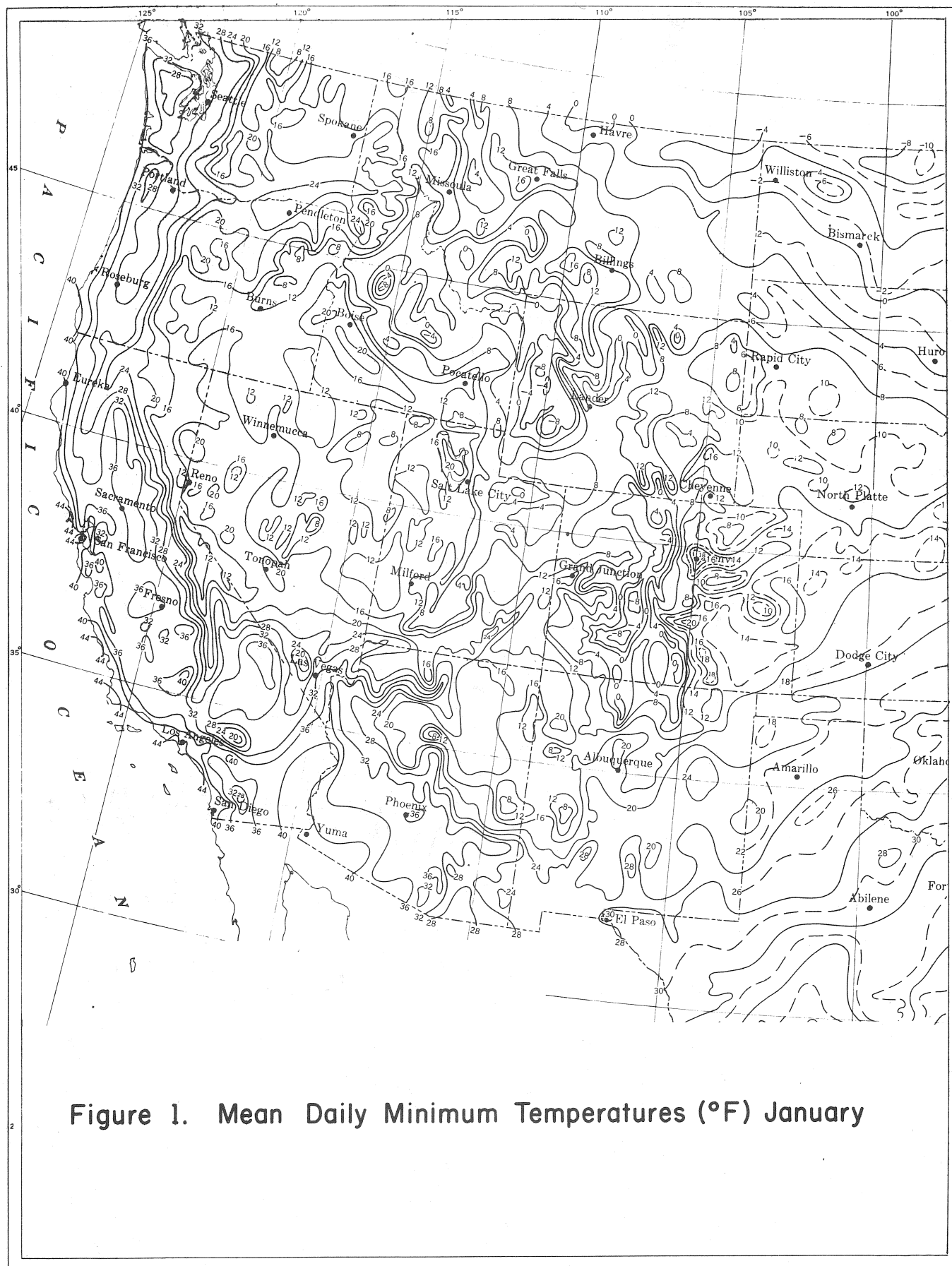


Figure 1. Mean Daily Minimum Temperatures (°F) January

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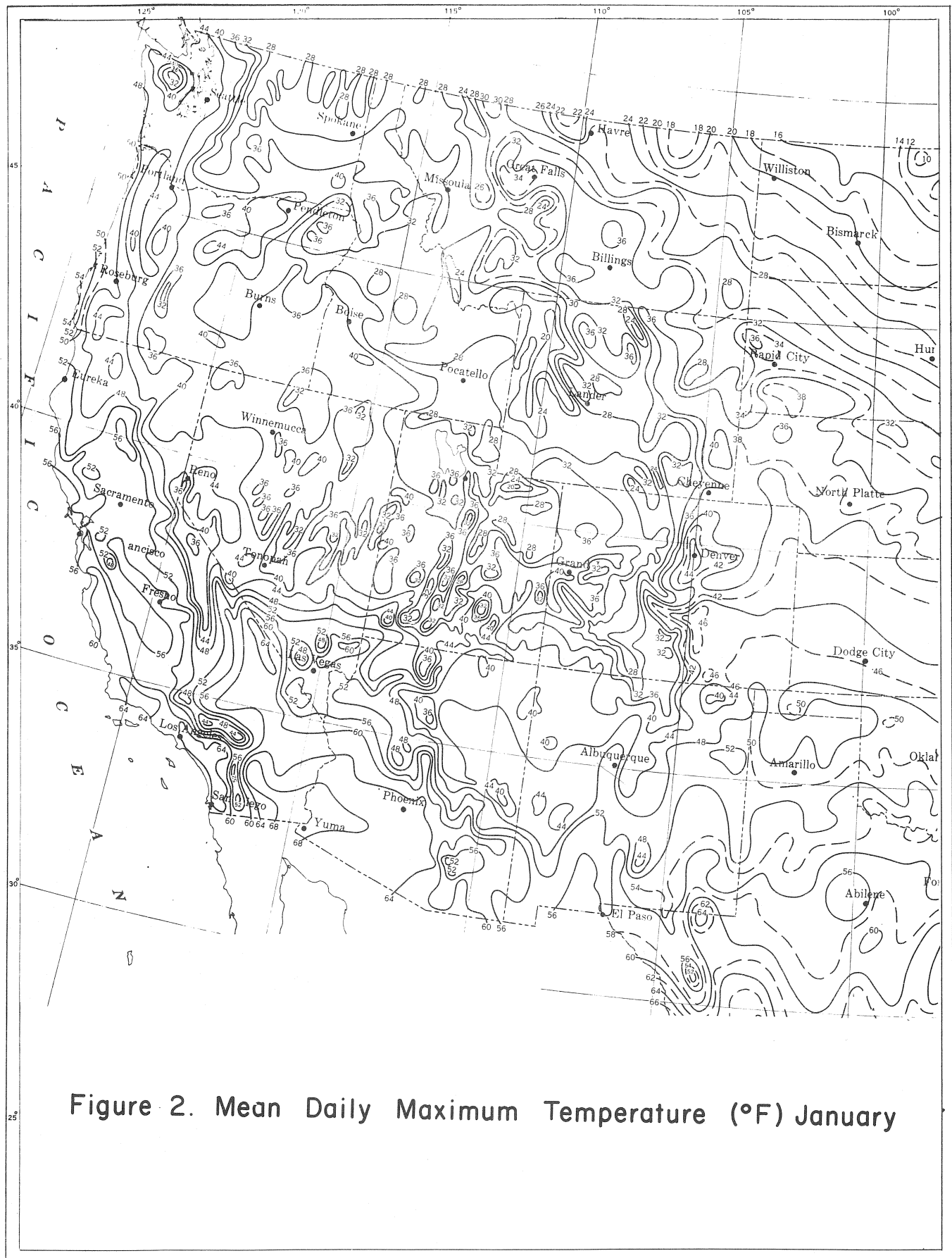


Figure 2. Mean Daily Maximum Temperature (°F) January

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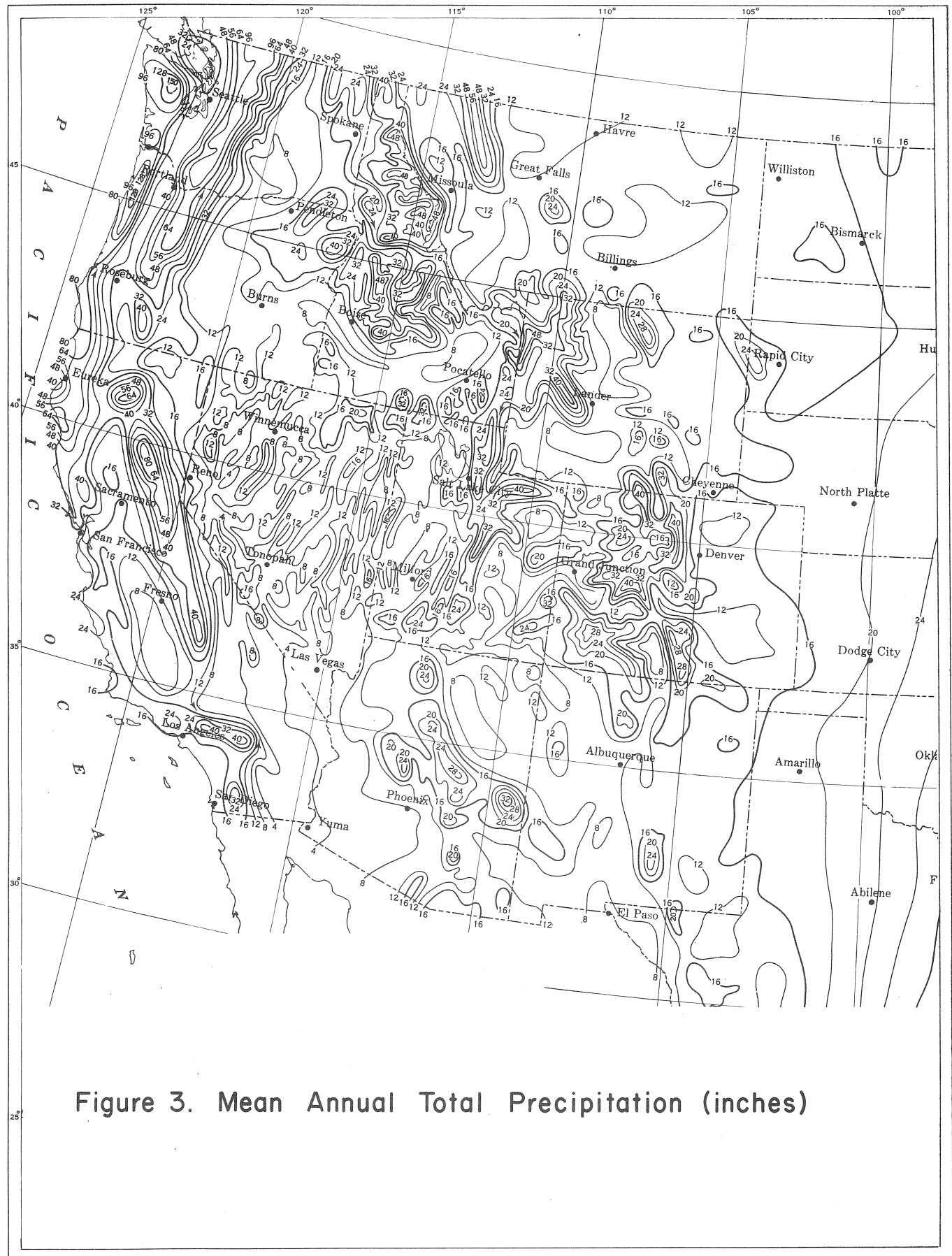


Figure 3. Mean Annual Total Precipitation (inches)

clarification geographically of the areas within their state requiring special consideration for frost affects.

A different approach to the frost effect problem appears immediately. All of the western states acknowledge that frost must be given consideration throughout a part of their state, however, only Colorado, Idaho, and Washington report that 100 percent of their state systems require special consideration due to frost.

The remaining states report limiting design considerations because of frost as follows:

| | |
|------------|---|
| Arizona | Northern half of state |
| California | Mountain regions |
| Montana | Area west of the Continental Divide, north central area and any area of silty soil having a high water table. |
| Nevada | Northern half of state |
| New Mexico | Elevations above 6,500 feet |
| Oregon | All of the state east of the western foothills to the Cascade Mountains |
| Texas | Northwestern part of state |
| Utah | Areas where moisture and frost are conducive, about 25 percent of state |
| Wyoming | Only irrigated areas |

It can be seen from these answers that the approach to the frost problem varies greatly and the degree of frost susceptibility considered to require attention varies.

The use to which land is put, that is, forested, cultivated, irrigated, etc, is not recognized by Arizona, California, Idaho, Nevada, New Mexico, Oregon, and Texas. However, the remaining

states, Colorado, Montana, Utah, Washington, and Wyoming, recognize land use as it affects the elevation of the water table.

As would be expected, all states are designing their heavy duty concrete highways for all season unrestricted legal axle loadings.

All states except Wyoming consider their asphaltic concrete pavements adequate for unrestricted legal axle loadings. Wyoming uses the 5,000 lb. equivalent wheel load method of evaluating axle loading and does not believe this method adequately provides for frost. Other states using the 5,000 lb. equivalent wheel load for axle loading either believe it adequate or provide other means of adjusting thicknesses because of frost.

All states except Wyoming and Texas are reported to provide for unrestricted legal axle loading and operation for their intermediate roads. Again, Wyoming feels the 5,000 lb. equivalent wheel loading is inadequate. Texas, without further clarification, reports that restrictions are applied to some roads.

Several states have designed parts of the secondary road system for springtime load restrictions. Montana applies load limits if the ADT is less than 100 vehicles per day. New Mexico and Texas report applying restrictions to some roads and not to others.

Oregon and Idaho report studies for strength loss of soils or softening of the road bed during the spring. Oregon has reported their work in previous Highway Research Board proceedings and

Bulletins. This work was conducted for the Committee on Load Carrying Capacity of Roads and Airfields as Affected by Frost Action. Idaho conducted Benkleman Beam Deflection measurements during the summer of 1954 and spring of 1955 with a few isolated tests since then. Their original work was reported at the WASHO Conference at Phoenix in 1956.

Soil Considerations

The Western States were asked if they had established any criteria for a "frost susceptible soil" and any test or combination of tests to measure the degree of susceptibility. Conversely they were also asked if they had any criteria or tests to assure that soils were not susceptible to frost. Answers vary from "No" to all questions to some interesting and apparently very practical considerations.

The percentage passing the No. 200 sieve together with liquid limit and plasticity index tests appears to be the most usually accepted approach to determining if a material is frost susceptible. The classification "silt" was also noted as being a criteria for frost susceptibility.

The percentages passing the No. 200 sieve varied from a maximum limit of eight to a maximum limit of 25 for a non-frost susceptible soil. Generally, values less than 12 percent were reported as the maximum percentage passing the No. 200 sieve for base courses. Limiting values for liquid limit or plasticity index were not reported.

Colorado reports they consider all their soil as frost susceptible. Arizona has established maximum percentages passing the No. 200 sieve for base materials depending upon elevations with 12 percent permitted to an elevation of 2,500 feet, 10 percent to 3,500 feet, and 8 percent for elevations above 3,500.

Montana reports they consider A-1a(o), A-1-b(o), and A-2-4(o) soils least susceptible to frost. Utah reports that any sand or silty soil having in excess of 25 percent passing the No. 200 sieve as being susceptible. Washington limits the percent passing the No. 200 to 10 percent for base courses and considers lesser percentages as non-frost susceptible.

Soil Profile and Horizon Considerations

Consideration of the location of the frost susceptible soil within the soil profile and the subgrade is given by all but four states. It appears that possibly other considerations such as the depth to the water table, etc. are the governing factors in these four states.

States that consider the frost susceptible soils to require special consideration base their action on the position of the soil with regard to the subgrade. Idaho takes precautions to remove all top soil at the grade point and to further reinforce this area with granular materials. Montana uses a minimum of two feet of selected granular materials in the top of their embankments together with a thicker surfacing section. Other states report raising their grade line and wasting the frost susceptible soils or burying them in the lower portions of embankments.

The depth to the water table is given special consideration by seven states and four report the water table presents no problem. Most states reported raising the roadway grade line if the water table was high. It appears that the dividing line between a high and low water table is considered to be about four or five feet.

The states giving consideration to the water table elevation remarked that their consideration was based upon the influence of the water table on the moisture content of the soil.

Selective placement of soil is given consideration by nearly all states. Reasons given by several are to reinforce or strengthen the subgrade and to reduce the quantities of high type base. Several report that the poor soils are buried low in the embankment. One state reports that it is too costly to consider selective placement. Another reports that uniformity of the subgrade is stressed and still another that the poor soils are merely given added reinforcement with base.

The general specifications appear to be about evenly divided in requiring or not requiring selective placement of soil. Several states reported that the special provisions or plans provided for selective placement when desired. Only two states made a special note that payment for cross haul was made, although the question was not one of those asked and several other states may also do this.

Five states report showing on the plans the soils to be excavated and replaced due to frost susceptibility. Others remarked this

was done to increase the structural strength of the subgrade. It is important to note that several states report the soil areas are too extensive for this type treatment.

The quality of backfill material is mentioned in only two specifications, but several states provide for central laboratory, material engineer's, or other engineer's approval of the material to be used. It appears this is not a specification described material.

The use of a material to prevent intrusion of fine grained soils into the coarser base or subbase materials is reported by six states, of which three use the Corps of Engineers D15/D85 ratio of less than five as their control. One state uses a A-3 sand if available otherwise a bituminous membrane in the bottom surfacing course. Another specifies a material having at least 15 percent finer than the No. 40 sieve and 25 percent finer than the No. 10 sieve. This is required only when the soil has more than 65 percent passing the No. 200 and a PI or linear shrinkage greater than five.

Geometric Design Considerations

None of the states appear to have special geometric designs due to frost considerations. Several note they have widened or deepened their ditches to provide for snow storage. A few remarked they occasionally made slight changes for short sections.

None of the states have any special drainage design features specifically for frost areas, although occasionally special drainage using perforated pipe underdrains is used for lowering of the water table.

Use of Admixtures

None of the states appear to have used admixtures in any general way to control frost susceptible soils. One state reports their maintenance forces on occasion have used sodium chloride in an attempt to prevent frost heaves. One other reports using portland cement and lime to control PI and upgrade aggregates. It is known that several western states have used portland cement and bituminous materials to upgrade or stabilize base courses, although not specifically to reduce frost affects.

Design of Flexible Pavements

Seven of the twelve states have provisions for varying their design thickness requirements because of frost. The other states use a standard design throughout but make variations in design due to type of soil, water table, and other considerations.

Criteria used for design is geographic in five states, i.e., regions wherein frost is no problem are noted and not given any consideration for frost. Three states use the maximum measured frost penetration as criteria. Two of these set a minimum thickness of the pavement structure, pavement, base, and subbase equal to one-half the frost penetration unless the soil strength calls for a greater thickness. Colorado has a table of factors which gives added thickness requirements depending upon the penetration of frost and moisture conditions. See Appendix B.

Two states report an arbitrary thickness increase where frost considerations dictate - one state providing 2 inches of base, the other 4 inches.

Apparently design considerations are applied to all soils as only two states made reference to this factor. One reported designs applied to all soils having more than 10 percent passing the No. 200 and the other remarked they wasted soils of high PI or "bentonite" type soils.

Limitation of axle loads apparently are not considered in design for frost except by Wyoming who believes the equivalent wheel load method to be insufficient to provide for all season legal loads.

The use of material to prevent intrusion of fines into the subbase or base courses as a part of the total design thickness is common to all states except two. Further comments made indicate that the material was considered in the design only if better structurally than the subgrade material.

None of the states report making any change in the design thickness for cuts or embankments. One state reports increasing the thickness in cuts if the tendency toward a wet situation exists and backfilling with selected granular materials.

Embankments constructed from rock are capped with granular materials by eight of the 12 states. One reports using selected material only for construction purposes and one other reports inferior materials are avoided. Only two of the states report that no special materials were provided or attention given.

Design of Rigid Pavements

Only two of the western states have any different considerations in the design of concrete pavement over frost versus non frost susceptible soils.

Both states add additional subbase over frost susceptible soils even though both have used base material beneath the slab.

Two states use the same frost penetration criteria for their rigid pavement designs as they do for the flexible pavements using base or subbase to obtain the necessary thickness.

Four states consider the base and subbase as a part of the thickness design but furnish no details as to the manner applied.

Two states treat with portland cement the base or subbase beneath the concrete pavement to prevent pumping. One other state does this but not because of frost. It is realized pumping is caused by water and not necessarily frost but spring thaws seemingly provide the greatest water supply at any time and in this way can be associated with spring breakup.

States using portland cement concrete pavements do not make use of any special material to cap rock embankments other than suitable material for a leveling course.

Subbase and Base Courses

Four states report on their criteria for measuring frost susceptibility of subbase and base courses. Three of these use the same criteria as for crushed base materials, i.e., gradation and LL and PI. Only one state reports any specific test. This test was developed by Mr. C. H. McDonald of the Bureau of Public Roads and is reported in Highway Research Board Proceedings, Vol. 29, 1949, Page 392, "Investigation of a Simple Method of Identifying Base Course Material Subject to Frost Damage". They report that although the test is not very precise it has provided considerable information.

All states apparently pretest and designate sources of materials for subbase and base during the preliminary engineering phases. This approval is given to sources but one state reports frost considerations are not included in their approval.

Seven states report that the gradation taken together with the Atterburg limits or the sand equivalent determines the quality of the materials to be used. Some report that their standard specifications require the same limitations for percent passing the No. 200 and for liquid limit and plasticity index for subbase material as they require for crushed base materials.

Ten states report that subbase and base courses are carried full width and one other reports this is done when necessary for drainage. The ditch is also carried below the subgrade in nine of the states with depths reported from 0.5 feet to 3 feet. Two states did not answer.

Only one state reports using any admixture to control frost susceptibility of base or subbase courses. In this instance they permit 20 percent passing the No. 200 sieve and use cement or lime to stabilize the material if it is above 12 percent or the plasticity index is above six.

Structures

Very limited information was obtained regarding frost susceptible soils or backfill materials. Those reporting placed footings below frost line and considered drainage of backfill materials of importance sufficient to mention.

General Comments on Practices of the Western States

The results of the questionnaire show that all the western states have some criteria that they use in design for frost susceptible soils. Most of the factors are incorporated into their over all design criteria but it is not always evident that certain requirements are essentially because of frost. This is particularly true in those states having a definite winter season throughout their entire state. Only those states having areas with limited or no winters throughout parts of the state apparently have recognized any major difference in designs.

Even though criteria differ throughout the states it appears to be mostly the means to the end that differs. Essentially all states strive to keep the better soils in the subgrade, elevate the grade line to reduce effects of the water table and keep a free draining subbase and base material over the subgrade. Criteria for the gradation limits and other properties do vary. However, as was pointed out previously, when the extremes of precipitation and climate are considered, this certainly must be no surprise. Those states having moderate to heavy precipitation with definite winters tend to have the most restrictive requirements for their subbase and base materials. Others with equally cold winters but limited precipitation apparently have found they can be less restrictive.

One factor that appears to be limiting special treatments of frost susceptible soil is the very extensive areas of materials that can be classified as definitely susceptible. In these

instances the design must be such that the roadway structure can carry all season traffic even though these materials are used. The use of a pavement structure, i.e., subbase, base, and surfacing equal to half the frost penetration is one approach used by two states. Others apparently find this too uneconomical or not necessary.

Realizing that the availability of materials for use in subbase and bases is limited in many areas it is understandable that the use of available local material, which experience has shown to give acceptable service, is used extensively if not almost entirely. Attention to the quality of bases and subbases and the upgrading of these materials by cement, lime, and bituminous materials is gaining in importance. All of the states apparently want to build roads capable of carrying legal axle loads all seasons of the year.

The factors involved in frost susceptibility are numerous. No one has developed a specific test for frost susceptibility as such but reliance is made on soil identification tests, depth to water table, position of the soil within the roadway grade, etc. in determining the design. This approach appears to be giving good results.

APPENDIX A

QUESTIONNAIRE
HIGHWAY PAVEMENT DESIGN IN FROST AREAS - DESIGN CONSIDERATIONS

Questions asked the various State Highway Departments are answered in the Tables below. The numbers at the head of the columns of the tables refer to the question numbers below.

1. GENERAL INFORMATION

- (a) What is the geographical extent of areas within your state wherein special consideration is given to frost effects in the design of pavements?
- (b) Does land use (irrigated tracts - forest lands, etc.) provide a guide or limit to the geographic areas given special consideration? If so, please explain.
- (c) Are pavements designed for all season unrestricted loading and operations on:

Heavy Duty Roads
Intermediate Roads
Secondary Roads

If other classification is used, please explain

- (d) Have you made any special studies regarding the loss of strength of soils or of the softening of the roadbed during the spring. Please give reference to any reports.

2. SOIL CONSIDERATIONS

- (a) Have you established any criteria for a "Frost susceptible soil"? If so, please furnish criteria.
- (b) Have you any criteria or specific tests or combination of tests to measure the degree of frost susceptibility? Please furnish details.
- (c) Have you any criteria or specific tests or combination of tests to assure that soils are not susceptible to frost? Please furnish details.

| State | 1(a) | 1(b) | 1(c) | | | | 1(d) | 2(a) | 2(b) | | 2(c) |
|------------|--|---|----------------------------------|-----------|-----------|---|---|--|--|-------------------------------------|--|
| | | | H | I | S | Other | | | Elevation Feet | Maximum Percent | |
| Arizona | Practically $\frac{1}{2}$ state high enough elevation to require frost consideration | No - Altitude and soil analysis | Yes | Yes | Yes | | No | Cover frost susceptible soils with sufficient material that frost no longer is considered. Specify use of non-frost susceptible base | Elevation Feet Under 2500 2500- 3500 Over 3500 | Maximum Percent 12 10 8 | Grading and plasticity index |
| California | Primary Routes in Mountain Regions | No | Yes | Yes | Yes | | No | No | No | | No |
| Colorado | Entire State | Yes - irrigated lands or other land where ground saturated when frost present. Ref. Colorado Dept. of Hwys. Design Manual, Table 5-606.4 (See Appendix B) | Yes | Yes | Yes | | None | All soils considered susceptible | None | | None |
| Idaho | Entire State. Doubt special consideration given but do have few "built in" controls like percent 200 in base and an empirical soil number. | No | Yes | Yes | No | | Periodic Benkleman Beam Deflection measurements | A-4 - A-5 | No | | No |
| Montana | Northwest area west of Continental Divide. North central area in Milk River drainage & areas of high water table. | Yes - irrigated and flood irrigated areas Combination excess water, high water tables, and heavy silty clayey soils can cause heaves. | Yes | Yes | | Yes on secondary roads if over 100 ADT. | No - observation of past performance | No | Past experience with individual soil types | | Consider A-1a(o), A-1-b(o), and A-2-4(o) soils least frost susceptible. Percent passing No. 200 sieve, liquid limit plasticity index on both No. 40 and No. 200 fractions usual guide. |
| Nevada | Northern $\frac{1}{2}$ State | No - generally severity climate is guide - irrigated tracts considered where encountered. | Yes | Yes | Yes | | No | No | No | | No |
| New Mexico | Northern State. elevations over 6,500. | No - See 1(a) | Yes | Yes | | Secondary roads - varies | No | Yes - Silt tested to verify | Permeability and freeze-thaw | | No |
| Oregon | East of Cascade Mtns. western foothills | No | Yes | Yes | Yes | | Yes - See HRB Proceedings Vol. 28 & 34, Research Report 10 D - Bulletin 40, 54, & 96. | Soils having more than 10% passing No. 200 sieve | No | | No |
| Texas | Northwestern area only | No | Yes | | | Some intermediate & secondary are restricted | None available | No | No | | No |
| Utah | Limited to areas where frost and moisture are conducive - 20-25% of State. Aridity of State not conducive to detrimental frost action. | Provided use furnishes moisture to frost susceptible soils. | Yes | No Ans | No Ans | | No | Non - or slightly permeable fine sands and silts with more than 25% passing No. 200 sieve | No | | Field experience - believe tests alone will not show areas susceptible. |
| Washington | Entire State | Yes - irrigation water effect on ground water has increased areas where frost must be considered. | Yes | Yes | Yes | | No | Soil or aggregate with more than 10% Passing No. 200 sieve | No | | No |
| Wyoming | Areas with light to heavy irrigation | Yes - irrigated areas only ones with high water table. | Concrete Yes Asphalt No | | No | Asphalt pavement std. Section based on traffic count. | No | No | No | | No |

3. SOIL PROFILE OR HORIZON CONSIDERATIONS

- (a) Does the location of a frost susceptible soil in a horizon influence your design? Please explain.
- (b) Does the water table elevation with relation to the frost susceptible soil influence your design? Please explain.
- (c) Are requirements for selective placement of soil considered and provided for in design? Please explain and if possible illustrate.
- (d) Does your standard specifications provide for soil types (granular material) to be used selectively?
- (e) Do you show on your plans areas of frost susceptible soils which are to be excavated from below subgrade and replaced with suitable backfill?
- (f) Is the quality of backfill material used to replace frost susceptible soils specified in your general specifications or is choice of material left to your field engineers?
- (g) Do you have any criteria for the use of a choker or blanket course immediately over fine grained soils to prevent intrusion into a subbase or base material? If so, please give details.

| State | 3(a) | 3(b) | 3(c) | 3(d) | 3(e) | 3(f) | 3(g) |
|------------|--|--|--|--|---|---|---|
| Arizona | No | Water table is usually too low to influence frost action | No | In base and subbase only | No necessary | No answer | Varies with available material controlled by PI & No.200 specification. |
| California | Only in special cases such as I-80 in the mountains. | No | No - for structural requirements only. | No | No | Where applicable included in specifications for project. | No |
| Colorado | No | Refer Colorado Design Manual Table 5-606.4 (See Appendix B) | Yes - when practical poor soils placed in lower portions of embankments. | No | No | Neither | No |
| Idaho | Yes - Topsoil or frost susceptible soils at transition cut and embankments excavated, backfilled with granular material - drainage provided. Depth below finished grade is to bottom topsoil or twice depth of "ballast" section whichever is least. | Keep ditch bottom 0.5' below base or any select granular material. | Specifications require saving granular material for selective placement. Project design may call for use in capping embankments. | Yes, see 3(c) | Yes, See 3(a) | Only that it be granular sources investigated during project development. Field engineers choice. | Yes - If percent passing No. 22 exceeds 65 & PI or linear shrink exceeds 5. Blanket material must have at least 15% passing No. 40 & 25% passing No. 10. Place 0.25' to 0.40' thickness. |
| Montana | Yes - Use selected granular soils in top of embankment (Min. 2') also thicker surfacing section. | Yes - Construct higher embankment or protect surfacing course with sand choke or bituminous membrane. | No - Poor soils in lower horizons. Best soils on top. Pay crosshaul - placed in 8" layers. | No - covered by special provisions | Yes | Left to field engineers judgment | Yes - Use 5" of A-3 sand when economically feasible based upon piping ratio of 5. When sand not available use a bituminous membrane full width in bottom of surfacing courses consisting of 3" - 4" depth roadmixed with SD4 or MC3 plus top and shoulders of surfacing courses given 2 applications Bituminous treatment down through membrane course. |
| Nevada | Silt pockets or layers are removed or covered by free draining material. | Yes - Roadway elevated above watertable elevation and placing free-draining base material above subgrade below surfacing. | No - Control is in base Thickness - poor soils given greater thickness. | Yes - Thicker base courses | Yes - Generally in high water table areas. | Quality of backfill specified - obtain from roadway cuts or borrow sources. | No |
| New Mexico | Yes - Grade line kept high to avoid moisture in embankment - special pitrun material may be used. | Yes - Higher water tables cause greater susceptibility. See Question 2. | Yes - uniformity cannot otherwise be obtained. | No - Plans have notes indicating where conditions warrant selective placement. | No - See 3(c) for method used. | No - selection by project engineer based upon criteria from preliminary soil testing. | No standard - on high type roads a layer of cement treated base is often used over fine silty clays. |
| Oregon | Yes - if soil in subgrade zone. | This is not a problem | Yes - if free-draining granular material is used in subgrade to reduce base rock requirements. | Yes | Yes - in particular instances | General Specifications | Corps of Engineers criteria for filter material. |
| Texas | Yes - where experience indicates. | No | Yes - where economically feasible. | Yes | Yes - under special conditions. | Not in General Specifications. | No specific criteria |
| Utah | If location of soil and moisture conditions are such as to require. If soil 4' below final grade not considered. | Yes - frost penetration without available moisture does not produce serious subgrade failures. | Yes - Well graded granular materials as subgrade reinforcement. Thickness these materials plus base and surfacing roughly equivalent frost penetration | Yes | No - Generally areas are too extensive - Treatment is prescribed in design recommendations. | No - When specified central laboratory determines type and quality. | Not in Specifications. Central laboratory determines if warranted and based on type and quality of materials economically available. |
| Washington | Yes - Avoided, wasted or buried or covered with adequate depth frost free material where they must be used. | Yes - If water table is expected within 5 feet of subgrade elevation frost design called for if frost susceptible soils involved. | Yes - See 3 (a) | Not specifically for frost - Usually covered in special provisions for project. | See 3 (d) | Not in General Specifications. Approval of Materials Engineer required. Quality see 2(a). | 15% size of Surfacing less than 4 to 5 times 85% size foundation material. |
| Wyoming | No | Yes - Water table elevation used determine where soils could be susceptible. Rain-fall, frost action, water table and general conditions used to determine final design. | No - Would make costs prohibitive | Yes - Special granular backfill used around culverts and specified drainage areas. | Generally No | No | No - However, used in certain areas. |

4. DRAINAGE

- (a) Are different geometric sections used in areas subject to frost problems than in non-frost areas (ditch depths, shoulder slopes, etc.)? If any, please describe.
- (b) Are any special drainage features or controls, if any, used in conjunction with your subgrade in frost areas versus non-frost areas? If so, please explain.
- (c) Are any special drainage features or controls, if any, used in conjunction with your subbase or base materials? If so, please explain.

5. USE OF ADMIXTURES

- (a) Have any admixtures been specified to control frost susceptible soils?

1. Calcium Chloride
2. Sodium Chloride
3. Bituminous materials
4. Portland cement
5. Lime
6. Sulphite Liquors
7. Other

- (b) Please describe your success with the use of admixtures, i.e., degree of increased support attained, duration of effectiveness, control frost heave, etc.

[illegible]

6. DESIGN OF FLEXIBLE PAVEMENT STRUCTURE THICKNESS (Pavement, base, and subbase)

- (a) Do you have any differing criteria for total pavement structure thickness in frost areas versus non-frost areas? Please explain.
- (b) If any differing criteria is used, is it applied to soils types generally or to any specific soil type? Please explain.
- (c) If limited axle loadings are provided for, how are these adjustments made in your design?

- (d) Do you consider any choker or blanket course used as a part of your total pavement structure thickness?
- (e) Do you vary pavement structure thicknesses for embankments versus cuts for the same soil types? Please give criteria if any.
- (f) Are any special materials specified to be used in capping rock embankments? Please give details.

| State | 6(a) | 6(b) | 6(c) | 6(d) | 6(e) | 6(f) |
|------------|---|--|--|---|---|---|
| Arizona | Standard design thickness | No answer | Not limited | Considered part of total thickness. | No | Attempt to avoid inferior materials - Material used depends upon material available. |
| California | No | No answer | No adjustments | Yes | For drainage purposes primarily; frost effects considered only in special cases. | Only for structural and construction purposes |
| Colorado | Total thickness of subbase, base course and surfacing is partly determined by depth of frost penetration (Ref. Colorado Design Manual - 5-606.4) (See Appendix B) | None | See Table 5-606.4 Appendix B | No | No | Yes - we use subbase material for leveling course. |
| Idaho | No | | | Yes | Extra thickness of granular materials provided in cuts if wet conditions are anticipated. | No - Specifications provide for using "approved granular materials". |
| Montana | No - Use HRB Group Index for thickness design with thicker bases over poorer soils. | Applied to all soil types & group indexes modified by local soil and moisture conditions. | Design for 20 years Projected traffic type and volume. | Yes - for choke course but not for blanket course of granular material. | No - Use same thickness | Variable - Depending on local conditions and type of rock. |
| Nevada | On Interstate projects total base and surface thickness is increased 4 inches in northern 1/2 of State or in frost areas. | Total base thickness is increased over minimum where poor soils are encountered. Determined during design from soil samples. | No | No | No | Yes - granular material specified and used as a cushioning material to cap rock fills and cuts. |
| New Mexico | Regional factor for thickness of Pavement Structure. | Applied to soils generally | Reflected in Traffic Index | Yes 3(g) | No | Yes - subbase or base course is used to level out rock cuts and fills, to profile grade. |
| Oregon | In frost areas total pavement structure equal to 1/2 frost penetration if exceed "R" Value for Soil. | All soil, if 10% or more material passes No. 200 sieve. | | Yes | No | No |
| Texas | No - due to limited depth of frost problem. | | | | No | |
| Utah | No - Extra thickness is applied in subgrade. Reinforcement with granular materials. | | | No - See 6(a) | No | Only a base leveling course. |
| Washington | Frost design thickness equal to 1/2 frost penetration in area for frost susceptible soils. | Only to frost susceptible soils. | | If it is of better quality or higher "R" value than subgrade on which placed. | No | No |
| Wyoming | Yes - frost areas noted on soils profile by field engineers - total thickness designed will be increased 2" over that required by Stabilometer. | Only on specific type such as "Bentonite". Soils having extremely high PI are noted on soils profile to be wasted. | Axle loading are limited and design done accordingly | When recommended included as part of total pavement structure thickness | No | Yes - Rock kept at least 2 ft. below profile grade on embankments. Special material used limited in maximum size and clay type soils are not to be used in the top 6" of the grade. |

7. DESIGN OF RIGID PAVEMENT STRUCTURE THICKNESS
(Pavement and Sub-base)

- (a) Do you have differing criteria for total pavement structure thickness in frost areas versus non-frost areas? Please explain.
- (b) If differing criteria is used, is it applied to soil types generally or to any specific type? Please explain.
- (c) If limited axle loadings are provided for, how are adjustments made in your design?
- (d) Is the sub-base course, blanket or choker courses considered as imparting any structural strength?
- (e) Are you providing for treating of the sub-base material with admixtures to prevent pumping? Please explain.
- (f) Do you vary the pavement structure thickness for embankments versus cuts for the same soil types? Please explain if used.
- (g) Are any special materials specified to be used in capping rock embankments? Please give details.

| State | 7(a) | 7(b) | 7(c) | 7(d) | 7(e) | 7(f) | 7(g) |
|------------|---|--|---|--|---|------|---|
| Arizona | No | | Not limited | Problematical | No | No | Attempt to avoid inferior materials - Material used depends upon types available. |
| California | No | | | No | Yes - All projects have 4" - 6" cement treated material directly under the PCC. | No | No |
| Colorado | None | | | Yes | No | No | Yes - Sub-base material used for leveling course. |
| Idaho | Have no design Standards | | | | | | |
| Montana | Usually Minimum 1 ft. of base course over free-draining embankment soils - Over frost susceptible soils 2 ft. blanket or sub-base or good granular material placed. | Soil types generally | Slab designed to carry expected traffic volumes with a 6" cement treated base - Additional base and sub-base courses are used to protect from frost heave with thicknesses based upon soil types or local conditions. | Yes - Slab is designed to carry traffic volumes and loads without additional base. | No | No | Use available material |
| Nevada | No answer | | | | | | |
| New Mexico | No | | Not limited legal only | Yes | Yes - 4" of cement treated base under PC pavement | No | Yes - See 6(f) |
| Oregon | Frost areas - Total pavement structure equal to at least 1/2 frost penetration. | See 6(b) | | Yes | No | No | No |
| Texas | No | | | | Yes - Not in connection with frost. | No | No |
| Utah | No | | | No | No | No | Gravel base materials as a leveling course. |
| Washington | See 6(b) | See 6(b) | No | Yes - See 6(b) | No | No | No |
| Wyoming | Yes - Areas of frost action thoroughly investigated. Standard rigid pavement designed and 4" of crushed base provided where frost is detrimental - additional sub-base to above used. | Yes - Applied to specific soil types in relation to water table. | Standard pavement design based upon overloads as outlined in PCA manual "Concrete Pavement Design". | No | No - Sub-base is a specification material. | No | See 6(f) |

8. SUBBASE AND BASE COURSES

- (a) Do you have any criteria for frost susceptibility of subbase or base materials?
- (b) Are sources of subbase materials pretested and designated for use?
- (c) Are sources of base materials pretested and designated for use?
- (d) What test methods and test limitations are specified to control quality of subbase and base materials for frost susceptibility?
- (e) Are subbase and base courses constructed full width from subgrade shoulder to subgrade shoulder?
- (f) Are ditch bottoms carried at a level lower than the subgrade on which any subbase is placed in frost areas? How far?
- (g) Are admixtures ever specified for use to control frost susceptibility of subbase or base materials? If used, what is your criteria, testing procedures and test value limitations?

| State | 8(a) | 8(b) | 8(c) | 8(d) | 8(e) | 8(f) | 8(g) |
|------------|--|--------------------------------|------------------------|--|--|--|---|
| Arizona | Use test reported in Highway Research Board Proceedings, Vol. 29, 1949, Page 392. Investigation of a simple method of identifying base course material subject to frost damage | Yes | Yes | Maximum % Pass No. 200 and plasticity index. | Yes | Usually | No |
| California | No | Not for frost action | Not for frost action | None | When necessary for drainage. | | No |
| Colorado | No | Yes | Yes | None | No | Not in all cases | No |
| Idaho | No | Yes | Yes | No quality criteria for frost. Have gradation and sand equivalent controls otherwise. | Yes | Yes 0.5 feet | No |
| Montana | Yes - limit % Pass No. 200 to 12% and LL to 35, PI to 6 by special provisions. | Yes | Yes | % Pass No. 200, LL & PI | Yes | Usually 1 foot | No |
| Nevada | No answer | | | | | | |
| New Mexico | No | Yes | Yes | None | Yes | No | No |
| Oregon | Yes | Tested and recommended for use | Tested and recommended | Standard Specifications for crushed materials | Yes | Yes - in special instances to 3 feet | No |
| Texas | No | Yes | Yes | None | Yes - generally | Yes | No |
| Utah | No | Yes | Yes | Use Standard AASHTO tests for gradation. Limit percentages fine sand and silt fractions in soils designated to use. | Yes | Yes | No |
| Washington | See 2(a) | Yes | Yes | Grading only See 2(a) | Nearly always except when special free-draining shoulder section is used | Ditch bottom carried 6 inches below subgrade elevation frost or no frost | No |
| Wyoming | Use Specification materials - these considered not susceptible. | Yes | Yes | Subbase crushed to pass 1 1/2" square sieve with less 20% pass No. 200 LL & PI meet base specifications. LL less 25 PI less 6. | Yes | Yes - ditch bottoms always below subbase. | Yes - when subbase or base has PI greater than 6, cement or lime used to improve quality. |

9. STRUCTURES

- (a) Are any special criteria employed for structures in areas subject to frost effects? If so, please explain.
- (b) Do you use a special backfill or embankment material that is non-frost susceptible adjacent to structures or culverts? If so, please give details.
- (c) Are any other treatments of soil made due to frost with regard to structures and pipe?

10. OTHER

Please add any comments you wish regarding Design Considerations relative to frost action in soils.

| State | 9(a) | 9(b) | 9(c) | 10 |
|------------|---|--|------|---|
| Arizona | No | All backfill for structures both in or out of frost areas shall have the sum of the % passing No. 200 and plasticity index not to exceed 23. | No | |
| California | | Granular material is required for all structure backfill. | No | |
| Colorado | Bridge footings placed below frost line. | No | No | |
| Idaho | No | Yes - granular material with less 5% pass No. 200 and Sand Equivalent of at least 70. | No | |
| Montana | No | Permeable granular material, less 15% pass No. 200 | No | Good embankment construction by layer placement with compaction control and selective placement of poor soils in lower horizons producing embankment uniformity together with adequate surfacing courses can eliminate detrimental frost action. We have found no cheap method of frost heave control, but have generally eliminated this condition by good embankment construction and adequate depths of surfacing materials. |
| Nevada | No Answers | | | |
| New Mexico | Footings below frost and use granular backfill. | Yes - Specifications require a specified granular backfill. | No | |
| Oregon | No | Yes - Backfill with a free-draining material. | No | |
| Texas | No | No | No | |
| Utah | Foundations below frost elevation. | Backfill conforms to Specifications for imported borrow. | No | |
| Washington | No | Yes - Standard backfill materials are non-frost susceptible. | No | |
| Wyoming | Footings are a minimum of 4 feet below ground line. | Yes - Replace poor material due to consolidation rather than frost. | No | Considerations are given in design to frost action in soils even though specific tests to determine this are not run. By having specifications on subbase and base and having embankment placed at 95% compaction we believe detrimental frost action is at a minimum. |

APPENDIX B

The Colorado Department of Highways, Design Manual, Section 5-606, Design Procedure for Flexible Pavements provides for varying the total thickness as follows:

"When (CBR) values are used on basement soils, the following procedure shall be used to determine the required thickness of subbase material:"

"The design curve to be used is determined by summing up the values assigned to the FROST conditions, moisture conditions and traffic conditions on Table 5-606.4."

"The gravel equivalent of the total thickness of subbase, base course surfacing and pavement is determined from Figure 5-606.4 by drawing a vertical line from the indicated (GRL) to an intersection with the designated design curve. From this intersection point, a horizontal line drawn to the left side of the chart will indicate the gravel equivalent of the combined thickness."

"The required subbase thickness is determined by subtracting from this gravel equivalent, the gravel equivalent of the base course surfacing and pavement."

Table 5-606.4

Design Curve Selection

FROST CONDITIONS

| | ASSIGNED VALUE |
|-------------------------------------|----------------|
| Penetration of 0" to 12" | 3 |
| Penetration of 13" to 24" | 5 |
| Penetration of 25" to 36" | 7 |
| Penetration over 36" | 10 |

MOISTURE CONDITIONS

| | |
|--|----|
| Arid or high table land not subject to standing water | 2 |
| Ground subject to occasional standing water during storms | 4 |
| Ground subject to saturation only during periods when frost is not present | 7 |
| Ground subject to saturation during periods when frost is present | 10 |

TRAFFIC CONDITIONS

| | |
|--|----|
| Traffic of 0 to 400,000 EWL | 0 |
| Traffic of 400,001 to 800,000 EWL | 1 |
| Traffic of 800,001 to 1,600,000 EWL | 2 |
| Traffic of 1,600,001 to 2,400,000 EWL | 3 |
| Traffic of 2,400,001 to 3,200,000 EWL | 4 |
| Traffic of 3,200,001 to 5,600,000 EWL | 5 |
| Traffic of 5,600,001 to 8,000,000 EWL | 6 |
| Traffic of 8,000,001 to 12,000,000 EWL | 8 |
| Traffic from 12,000,000 EWL | 10 |

SUM OF ASSIGNED VALUES

| | |
|-------------------------|-------------|
| From 0 to 8 | Use Curve A |
| From 9 to 13 | Use Curve B |
| From 14 to 18 | Use Curve C |
| From 19 to 24 | Use Curve D |
| 25 and over | Use Curve E |

DESIGN CHART FOR THICKNESS OF SURFACING & SUB-BASE COURSES

